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SUMMARY VERSION

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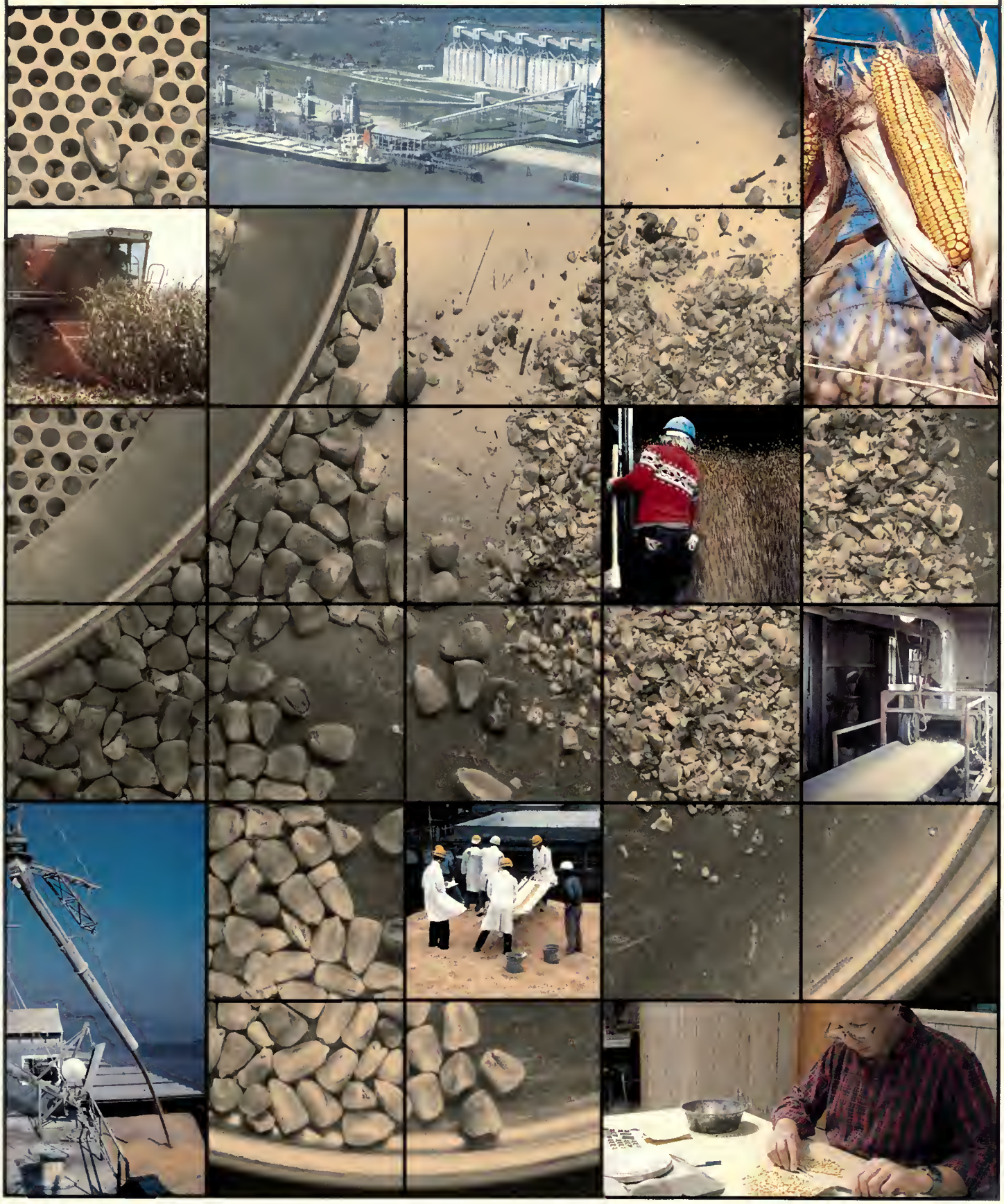
Changes in Corn Quality

During Export from New Orleans to Japan



Lowell D. Hill and Marvin R. Paulsen

Bulletin 788B

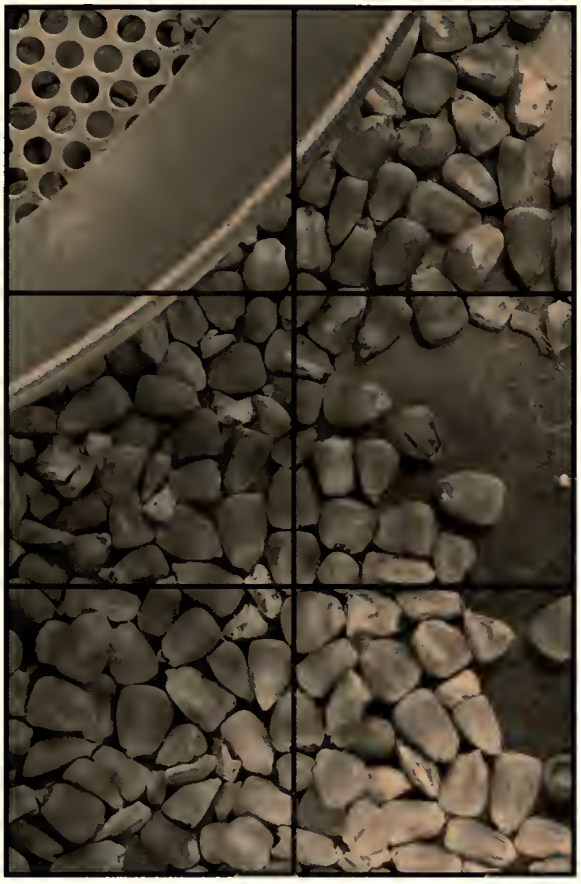
COMPANION TO THIS VOLUME

For the complete research report describing this project, including seventeen figures, twenty data tables, and a full discussion of the research methodologies, order Bulletin No. 788A, *Changes in Corn Quality During Export from New Orleans to Japan.*

SUMMARY VERSION

Changes in Corn Quality

During Export from New Orleans to Japan



Lowell D. Hill and Marvin R. Paulsen

Bulletin 788B ❧ College of Agriculture
University of Illinois at Urbana-Champaign
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June 1990

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The Market Channel Subjects Corn to Punishing Stresses

The quality of corn begins with planting decisions, when a grower chooses a variety with characteristics that will command a high market value. Corn quality begins to decline at harvest, where high-speed combines — a labor-efficient way to harvest — can damage kernels.

Intrinsic quality is determined at planting, when farmers select the variety to plant.

Corn quality is at its peak just before harvest.

Corn combines allow rapid harvest but often chip or damage the kernel.

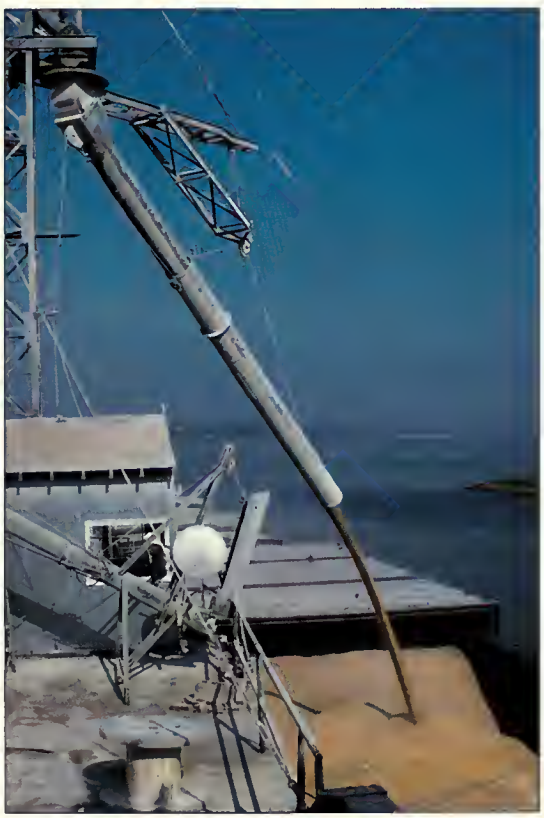
Most U.S. corn is harvested at moisture levels that are too high for safe storage; it must be dried artificially on the farm or at the country elevator. High-temperature dryers reduce the time required but also increase the kernels' susceptibility to stress cracks and breakage.

High-moisture corn may be dried on the farm (left) or at the country elevator (above) with high-temperature dryers.

Country elevators are the first stop in a long and complex market channel, receiving farmers' grain by truck.

Shipment by unit trains provides economical transport to river terminals or ports.

As the corn moves through the various stages in the market channel, it is subjected to many punishing stresses. Corn may be heated, frozen, elevated, and dropped many times before it reaches the final user. The impacts are often too much for the fragile kernels. The result is many broken kernels and fine particles.



Farmers and country elevators deliver corn to river elevators, where it is loaded in barges.

Nearly 50 percent of the corn destined for export moves on the Mississippi River system.

Barges are unloaded by marine leg at the port elevator.

Ocean vessels holding as much as 2 million bushels are loaded in as little as 15 hours.

Pneumatic spouts ("suckers") unload a vessel of U.S. corn in a Japanese port.

Clean-out of each hold requires assistance from an end loader in the hold.

Corn is transported from the vessel to the Japanese processor by barges . . .

coasters . . .

or trucks.

U.S. grain producers pride themselves on the quality of the corn they harvest, but in fact the quality of corn at foreign destinations is far less than on the ear in the farmers' fields. Starting with harvesting, the corn kernels undergo a variety of punishing stresses that cause physical and biological changes. These quality losses are especially dramatic when corn is shipped overseas in large, slow-moving ocean vessels.

Before corn leaves the United States, it is checked for damage, foreign material, and moisture and certified to meet or exceed the grade or quality level requested by the buyer. Foreign buyers complain, however, that the corn they receive is substantially lower in quality than that reported on the certificate. At some point in the market channel—after being certified by the USDA, FGIS, and before reaching foreign processing plants—the quality has declined.

To help U.S. producers and exporters learn what happens to corn while it is in transit, researchers at the University of Illinois undertook a detailed study of two corn shipments, both bound from the New Orleans port area to Japan. The project was designed to answer three main questions:

- To what extent does corn deteriorate during shipment under different environmental conditions?
- What factors cause the decline in quality?
- What courses of action can reduce or eliminate quality losses during shipment?

The researchers worked with Japanese importers, who selected the export elevator and nominated the vessel for the two shipments. By coincidence, the *Century Progress* was nominated for both shipments. In 1985, the vessel was loaded May 22-23 in the New Orleans port area with 56,895 metric tons (2.24 million bushels) of U.S. No. 3 yellow corn. It arrived June 28 in Chiba, Japan, via the Panama Canal and Long Beach, California. In 1986, the vessel was loaded March 20-21 in the New Orleans port area with 55,006 metric tons (2.17 million bushels). This second shipment followed a similar route but took slightly less time in transit, arriving April 22 in Kashima, Japan.

Researchers sampled the corn at each location in the market channel: from the inbound barges during unloading at the export elevator (only in 1986); in the export house, using a mechanical cross-cutting diverter on automatic timer; from the vessel during loading, using 10-foot compartmentalized grain probes; and from the vessel, barges, and coasters in Japan, using the same grain probes. Sampling rates and patterns were designed to give the most accuracy and the least possibility of bias.

Temperature sensors were placed in various spots throughout the hold to measure changes in the temperature of the corn mass and to determine how changes in the water and air temperatures affected the temperature of corn.

Some samples were analyzed even before they were taken off the vessel in Japan to make

sure the quality didn't deteriorate further while samples were in transit from Japan back to the University of Illinois. Other agencies and laboratories in the United States and Japan performed duplicate analyses on some samples to verify accuracy, repeatability, and representativeness of the samples and to provide more information.

Many people and agencies helped the researchers in sampling and monitoring quality changes:

- in Japan, customs officials, stevedores, inspection agencies, the quarantine authority, and a team of Japanese samplers;
- in the United States, the Federal Grain Inspection Service (FGIS) of the USDA, export brokers, plant managers, stevedores, and the Animal and Plant Health Inspection Service (APHIS) of the USDA, which gave permission to return samples to the United States; and
- on the vessel, the owners, the captain, and the chief engineers.

All samples were tested at the University of Illinois's Agricultural Engineering Grain Quality Laboratory. A number of other agencies also performed analyses:

- in Japan, the Japan Grain Inspection Association (JGIA);
- in the United States, the FGIS at its office in Lutcher, Louisiana, and the Champaign-Danville Grain Inspection Department (CGID) in Champaign, Illinois. The University of Illinois's Entomology and Plant Pathology laboratories analyzed samples from the 1986 shipment for mold and insect infestation.

Before loading the vessel, the research team, stevedores, the plant manager, the ship's master, and FGIS personnel met to coordinate the sequencing of loading and sampling. They coordinated the grain depth required during sampling with (a) the stowage plan in each hold, (b) the balance of weight and ballast among holds in the vessel, (c) the loading schedule of the elevator, and (d) the schedule of stevedore shifts. Team members scheduled the timing of sampling and analysis in the elevator, on the outbound belts, and from the inbound barges to keep a full sampling team available in the hold. Twenty minutes was often the maximum time available for sampling, bagging, and tagging sixteen two-probe samples from a layer in one hold. Accurate records and identification of every sample accompanied all of this activity.

Similar coordination and planning was required when the vessel reached its destination. When the vessel was several hours from the harbor, the research team contacted the vessel masters by ship-to-shore communications to plan the unloading sequence of each layer and each hold. They contacted receivers, as well as the owners and operators of barges, for permission to take samples of their grain. More than one destination was receiving grain from the vessel, and the research team mapped out which holds to sample in what sequence to avoid creating imbalance on the vessel. Pneumatic unloaders had to be removed from the hold at each 10-foot level before the sampling team could enter the hold. And in 1985, after all plans were finalized, a typhoon required the vessel master to close the hatches and move back out to sea. This disrupted the

entire sequence and generated a second round of adapting research plans.

Despite the difficult and shifting planning process and the associated negotiations, the researchers did not compromise the important basic principles:

- samples must be representative of the sublot from which they were taken;
- identification of samples must be kept inviolate and the samples kept intact;
- samples must be selected randomly and without bias with respect to quality;
- analysis must follow established laboratory procedures and statistical principles; and
- the objective of comparing samples from the origin and from the destination must be fulfilled by matching holds and samples.

The results of this study confirm those of previous studies. The major problems with corn shipments are (a) an excessive number of broken kernels at the destination that, according to official grades, would be labeled broken corn and foreign material; (b) heating and mold growth during the time the vessel is in transit; and (c) segregation on the factors of particle size, broken corn, and moisture within the hold of the vessel during loading and unloading.

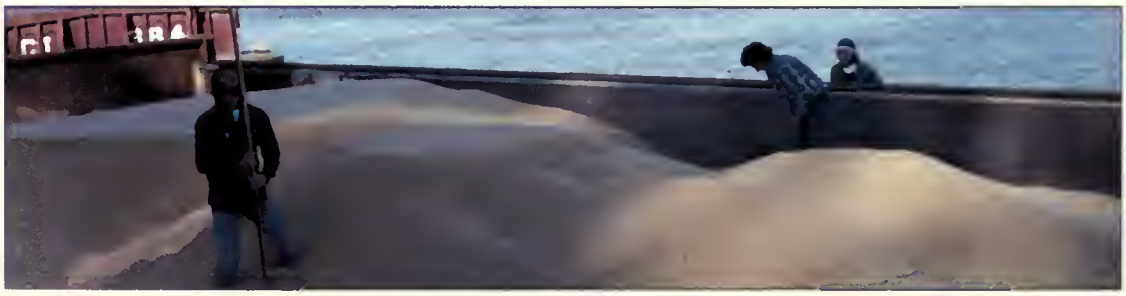
To assure buyers that the corn shipped has the quality specified in the contract, corn is inspected and graded at each point in the market channel. The research reported in this study supplemented the usual quality assurances given by normal inspection procedures.

Research Procedures Supplemented Normal Federal Quality Inspections

Elevator employees usually weigh and grade corn receipts and shipments as they arrive.

Elevator employees weigh and grade corn when it arrives from the farm and again when it leaves the elevator. The barges may be sampled by probe after loading, or after they reach the exporting elevator. When barges are unloaded at the port elevator, the corn is binned according to quality — this allows the exporter to combine different bins to meet the buyer's grade specifications.

Mechanical probes may be used to obtain samples from farmers' trucks and wagons.



Samples of grain from loaded barges must be taken by grain probes.

Grain probes provide a vertical cross-section sample representing the entire lot.

A large number of individual bins is required at the export elevator to allow separation of different qualities.

Each sample is analyzed by a licensed inspector to ensure an accurate, objective grade on the inspection certificate.

A mechanical diverter-type sampler, as required by law, samples the corn during loading of the vessel. The machine takes a few kernels from the grain stream at frequent intervals. The numerous, small samples are combined into a single sample, representing a sublot of about 60,000 bushels. Federal inspectors and elevator employees check each sample for moisture, foreign material, damage, test weight, and signs of insects.

Many small samples are diverted from the grain stream by an automatic sampler during loading, to provide a representative sample of each sublot.

After the corn is certified to meet contract specifications, high-speed belts carry the kernels to a waiting vessel. Almost immediately the corn's quality declines from the level certified, as the loading process subjects the kernels to impact stresses that increase breakage.

Results

The main reason foreign buyers receive reduced-quality corn is not because substandard corn has been shipped but because the corn deteriorates between the export houses and the foreign destinations. And the deterioration is caused by *normal handling procedures within legal limits of the regulations governing grading and loading*. Corn in these two shipments, loaded under supervision of elevator personnel, FGIS personnel, and University of Illinois researchers from four disciplines, was within the contract grade at the time of loading but was several grades lower on the factor of BCFM by the time it was unloaded at destination.

Some solutions to quality deterioration lie with the contract specifications of foreign buyers and the practices generated by current U.S. grading and pricing systems. Specific suggestions for improving quality are given at the end of the following sections.

Broken Corn and Foreign Material

In both shipments, the quality of the corn delivered to Japanese processors in the coasters, barges, or trucks was similar to that loaded on the vessel in New Orleans. The No. 3 yellow corn loaded at New Orleans would have been delivered as No. 3 yellow corn to the importing elevator in Japan, had not BCFM increased. BCFM was the only grade factor that changed significantly between origin and destination. Several processors received sample grade corn as a result of the increase in the average BCFM on the vessel and of the variation in BCFM among the many relatively small sublots delivered to the final point in the market channel. BCFM increased at each stage in the market channel where handling created impact. Stress cracks induced by high-temperature drying and rough handling resulted in kernels that were highly susceptible to breakage in subsequent handling. The routine transfer of grain in and out of vessels fractured the kernels, increased the BCFM, and increased the proportion of fine material and dust.

The average BCFM of all inbound barges in the 1986 shipment was 2.9 percent. Unloading at the export elevator added slightly to the breakage, resulting in an average of 3.1 percent. This increase was not statistically significant. Loading from the export elevator into the vessel increased the BCFM by 1.52 percentage points in the 1985 shipment; 2.73 percentage points in the 1986 shipment. Unloading from the ocean vessel at the Japanese destination port into barges and coasters added an additional 2.71 percentage points of BCFM on the average in 1985; 2.69 percentage points in 1986.

Associated with the increase in BCFM was an increase in the fine materials and dust. The handling during loading and unloading increased the percentage of dust from 0.35 percent on the conveyor belt at the loading port to 2.62 percent in the coasters and barges at final destination in the 1986 shipment. In both shipments the percentage of whole kernels

generally declined with each successive handling. In 1985 conveyor belts brought the corn directly from storage bins to the loading spouts and into the vessel. In 1986 the corn was conveyed from storage bins to shipping bins and then moved to the loading spouts and into the vessel. The impacts associated with the handling in 1986 resulted in a greater increase in BCFM than occurred in the 1985 shipment.

Although these two shipments contained corn with similar intrinsic breakage susceptibility characteristics, the colder temperatures during loading in 1986 (15°C compared to 22°C in 1985) and the additional handling through the shipping bins resulted in an average increase in BCFM between belt and vessel of 2.73 percentage points. This contrasts with only 1.52 percentage points in the 1985 shipment.

The handling throughout the exporting and importing process reduced the percentage of whole kernels, increased the percentage of BCFM, increased the amount of dust and fine materials, and caused segregation among sublots.

Suggested courses of action

Loading and unloading impacts result in increased broken kernels, primarily because of the internal stress cracks created in the corn during harvesting and drying on the farm. Each successive handling increases the amount of breakage and the percentage of kernels with stress cracks. There are two general courses of action that could improve quality through reduced breakage.

Gentler handling. This includes lowering the loading spout close to the surface and reducing the velocity of the corn during loading of the ocean vessel and the use of inclined belts wherever possible in the export house. Pneumatic unloading equipment at the destination and the use of end loaders for cleanup at the bottom of the hold also add to the breakage. Any procedures that reduce the number of times the corn is handled between the farm and the final user's plant will reduce breakage and susceptibility to breakage. Changes in equipment design to reduce kernel velocity could reduce the force of the impact, but it would also increase the cost of marketing. There are new unloading devices such as the Simporter that handle the corn more gently. Modern export houses have been designed to minimize impacts. For example, the use of large buckets on the marine legs moving at a slow speed, rather than many small buckets moving at a high speed, reduces the force of impact and amount of breakage.

More durable corn. It is possible to produce corn that will better withstand the impacts of the normal handling in the market channel. Low-temperature drying, harvesting at lower moisture contents, and selection of varieties more resistant to breakage are all recommended practices to increase the ability of the corn kernel to withstand handling in the market channel. Although this information is generally available to farmers, there are few economic incentives to encourage them to change harvesting and drying practices or to select different varieties. Introducing a measurement for breakage susceptibility at the country elevator before the corn actually breaks would reward farmers who produce corn with low breakage susceptibility charac-

teristics and penalize those who are using drying temperatures or harvesting methods that will result in more breakage in subsequent handling.

Both alternatives for reducing breakage have a cost associated with them, and the market at the present time does not provide economic rewards or incentives for adopting these practices. Incentives require changes in the grades to identify breakage and susceptibility to breakage separate from foreign material, but more importantly it requires changes in the marketing system so that price differentials will be associated with these characteristics.

Heating and Mold Growth

Conditions of time, temperature, and moisture within the hold of the vessel contribute to problems of heating and mold growth. The presence of mold and fungi was not serious enough in either shipment to concern the Japanese processors or to result in a change in grade. However, mold growth was evident in both shipments, and the temperature sensors in hold 5 identified a definite pattern of temperature changes, partially explaining increased mold growth during transit. Increased temperatures resulting from external sources, as well as respiration of molds within the corn mass, resulted in sufficient internally generated heat to create problems with unloading the 1985 shipment. In 1986, the effect was also evident in hot spots scattered throughout the hold, even though the deterioration had not progressed to the point where it created problems with unloading.

In the 1986 shipment, the percentage of kernels showing fungal infection was calculated for each layer of holds 3 and 5. In hold 3, the average values of the five layers showed consistently higher levels of infection at destination than were found at origin. The percentage of kernels infected with *Fusarium* and *Aspergillus glaucus* at destination was approximately double the level at origin, and the increase was consistent for nearly every layer. The increase in fungal infection was statistically significant for all species except *Aspergillus flavus*. Because of the extreme variability among samples, researchers could not determine a significant difference among layers.

Moisture Content

Mold growth and heating are primarily the result of moisture and temperature conditions conducive to the development of the various species of molds and fungi. An analysis of average moisture content and variation among kernels was conducted to determine the effect on quality. The contract for each shipment specified a maximum average moisture content of 15 percent. Although the average moisture may indicate that the grain is safe for storage or transport, the sample may contain a range of moisture contents that provides conditions conducive to rapid deterioration. A blend of various moisture levels will still meet contract specifications based on average moisture—even though individual kernels may significantly exceed the range for safe storage and transport.

Analyses of the 1985 origin samples showed a range of five percentage points of

moisture content in individual kernels, from 12.7 to 17.5. The accuracy of the individual kernel measurement is indicated by the average moisture content of 15.1 percent for the individual kernels, compared with the average moisture content of 14.8 percent reported for the 15,000-bushel components from which the samples were drawn.

No bin in the export house contained corn with average moisture content as high as 17.0 percent or as low as 13.0 percent. This suggests that the moisture range in the samples was present before loading the grain into the export house. This conclusion was validated in the 1986 study by measuring the individual kernel moisture of samples from inbound barges. Although only 1.7 percent of the kernels contained 17 percent or higher moisture, the presence of these high-moisture kernels indicated the lack of complete equilibration during the time the corn was in transit to the port or was in storage bins in the elevator. Additional blending at the port elevator created 50,000 tons of grain with very uniform moisture levels, comparing one sample with another. However, analysis of the moisture contents of single kernels within these samples revealed a significant quantity of high-moisture grain loaded on the vessel. An example helps put the 1.7 percent high-moisture kernels in perspective. In a 2-million-bushel (50,800 mt) shipment, the results of this limited study indicate there would be 34,000 bushels (863 mt) of corn at moisture levels of 17 percent or higher. This is not a stable situation in a static grain mass held for three to five weeks in the hold of the vessel.

Temperature Effects

Temperature sensors were placed in hold 5 in both shipments and hold 6 in the 1986 shipment to determine the effect of external changes in temperature (e.g., during passage through the Panama Canal when air temperature exceeded 30°C) on the corn temperature and the growth of molds and fungi.

Corn temperatures automatically recorded by the sensors during the voyage revealed the insulating effects of corn. Air, water, and fuel tank temperatures all had a definite effect on the temperatures of corn near the heat source; but as distance from the source increased, the temperature rise was less and the time lag increased. The sensors identified an average daily air temperature of 30°C in the hold above the corn when the ship passed through the Panama Canal. After the vessel had left the canal zone, air temperatures decreased while corn temperatures one foot below the surface continued to rise for several days, showing a delayed reaction to temperature change as the depth increased.

Temperatures on the floor above the fuel tanks of hold 5 showed the same type of delayed reaction, even with the extremely high temperatures experienced during the transfer of fuel. The insulating effect of the corn absorbed rapid fluctuations in the floor temperature, which increased to nearly 55°C (131°F) for a short time as steam coils in the tank heated the fuel. Temperatures two feet above the floor over the fuel tank increased with a lag of several days. Up to a distance of one foot from the heat source, the corn cooled as the floor surface cooled. At three feet above the floor, however, there was a slow but steady

increase in temperature throughout the voyage as a result of the time required to transfer heat from the source through the corn. Corn temperatures never reached the source temperature at any location.

Effects of Time, Temperature, and Moisture on Mold Growth

Unlike the results of the 1985 study, the conditions of temperature and moisture in 1986 did not give rise to rapid and spontaneous heating throughout the hold. The necessary moisture and microflora were present in both cases, and the high-temperature sources were the same (the fuel tanks and the Panama Canal climate). The difference was in the original temperature of the corn at the time of loading the vessel: 22°C in 1985, compared with 15°C in 1986. The lower temperatures of the corn in the vessel in 1986 reduced the effects of the high air temperatures in Panama and kept the majority of the corn in the vessel below the critical point for time, temperature, and moisture required for generating microbiological heat. The presence of several "hot spots" in the 1986 shipment indicated that heating from biological activity had started in some isolated areas and would have increased if more time had passed before unloading.

Mold damage is the result of the interaction between time, temperature, and moisture content of individual kernels as well as the average moisture content of the entire shipment. Previous research has demonstrated that each of these factors has a significant impact. The 1985 shipment was loaded under conditions of higher corn temperature, a wide range of individual kernel moistures, and an extra four days between loading and unloading the vessel. Damage from mold and biological heating was much greater than in the 1986 shipment. The moisture variability among individual kernels was similar in both shipments, and the research demonstrated that the high-moisture kernels were the ones where mold and heating progressed most rapidly. Although the outside temperatures of air and seawater influenced the temperature of the grain mass, this effect was damped by the insulating effect of the corn mass. Blending of corn with different moisture contents begins at the time the corn is harvested in the field. Additional blending is unavoidable throughout the market channel as different sources of grain are commingled to meet the contract specifications. The diverse moisture levels and environmental conditions combined with long-distance transport inevitably generate the development of mold and fungi. When temperatures in any part of the grain mass reach the critical point, the growth of mold accelerates.

Suggested courses of action

Too many variables control the growth of microflora (including storage history) to accurately predict the condition of a shipment at arrival. However, controlling four variables can minimize the risk of spoilage: (a) the average moisture; (b) the maximum moisture of any kernel; (c) the temperature; and (d) the amount of time in transit.

The average moisture content is controlled by the contract, generally established by the importer. Moisture variability is controlled in part by the practices of country elevators and exporters. The time in the vessel during transit

and the temperatures of the corn and outside air are generally beyond the control of either the shipper or the receiver. But the corn temperature (which differs according to the season and the port of loading) should be taken into consideration when setting contract limits on average moisture.

Price penalties for blending widely different moisture levels would reduce the problem of moisture variability. Such economic incentives are dependent on development of technology for measuring individual kernel moisture at each point in the market channel and on the willingness of buyers to attach price differentials to the measurements. Self-imposed limits and educational efforts may be effective in many cases. For example, the National Grain and Feed Association has recommended that elevators not blend corn with a spread of more than four percentage points between the highest and lowest lots. This may reduce the quantity of high-moisture kernels in the market channel, but it does not remove the variability that exists within a field of corn at the time of harvest. Improved drying practices and more uniform moisture from high-temperature dryers (including changes in dryer design) would also reduce the moisture variability.

Segregation

Segregation is a problem whenever the vessel or hold is subdivided among different buyers. If no effort is made during unloading to blend corn from different holds or different areas of a single hold, one buyer may receive a sublot very different from the average quality of the vessel. Both cargoes of the *Century Progress* were distributed among many feed manufacturers and starch processors.

Serious segregation problems exist only for the factor of broken corn and foreign material or particle sizes. No other factors appear to be severely segregated during loading or unloading. Dust and finer materials, although not a separate grade factor, are concentrated in areas where the loading spouts are placed during loading; whole kernels and large particles tend to segregate around the perimeter of the hold.

In the 1986 shipment segregation and variability were identified, starting with average values for barges as they were being unloaded. Blending by the exporter during loading of the vessel lowered the range of BCFM from 2.8 to only 1.2 percentage points between highest and lowest sublots.

Segregation increased dramatically during loading of the vessel. Two-probe samples taken from hold 5 during loading had a minimum value of 3.76 percent BCFM and a maximum value of 13.72 percent BCFM, giving a range of 9.96 percentage points. The single-probe samples taken in hold 1 had a range of 11.61 percentage points, from a low of 2.60 percent to a high of 14.21 percent. A comparison of the variances, using only two-probe samples, showed a statistically significant increase in segregation between the belt samples and samples from the vessel.

To help researchers achieve uniform sampling, the loading spouts were moved frequently during loading. This probably lessened the usual "spout line" effect created under normal loading conditions and reduced the extremes of segregation. However, the samples taken from the perimeter quadrants in

hold 1 averaged 1.4 percentage points lower in BCFM than those from the inside quadrants—a statistically significant difference. This would tend to support the belief that most of the smaller particles stayed in the spout lines, and the larger particles (whole kernels and large broken pieces) tended to flow to the outside.

There is no basis for expecting any change in segregation during transit. Previous studies have shown no evidence of fines shifting in a stationary grain mass, although the vertical height of the grain mass in each hold is reduced by one to four feet as a result of settling and packing during the ocean voyage. This conclusion was reinforced by data obtained from hold 5, which was sampled in an identical manner during loading in New Orleans and unloading in Japan. There was no change in average BCFM values or in variability among samples.

Segregation persisted after unloading in the 1986 shipment. The data indicated that segregation within a coaster sublot remained after unloading the vessel but varied among barges or coasters, depending on the procedures followed during discharge of the cargo. The range among coasters in average BCFM was only 1.95 percent, indicating a dramatic reduction in variation when dealing with sublots as large as a full coaster. The blending that occurred when several pneumatic unloaders were unloading simultaneously from more than one hold also reduced the segregation among barges and coasters.

Suggested courses of action

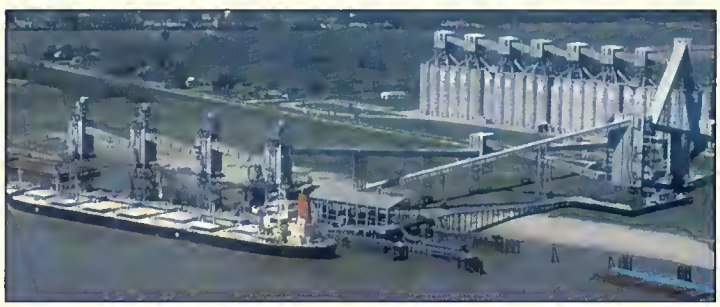
Frequent moving of the spout during loading not only maintained a level distribution within the hold but also reduced segregation. Thus, segregation can be reduced by small efforts on the part of both the importer and exporter. However, unless deliberate efforts are undertaken to reblend during or after unloading at destination, the segregation on particle size will continue to be a problem, especially where the shipment is distributed to a large number of final users.

University of Illinois researchers began sampling procedures at the export point in the market channel. Loading of the hold was interrupted to allow sampling in 10-foot layers. To monitor how outside temperature changes affected the corn, researchers placed temperature sensors strategically throughout one hold. The sensors were connected to automated recording devices.

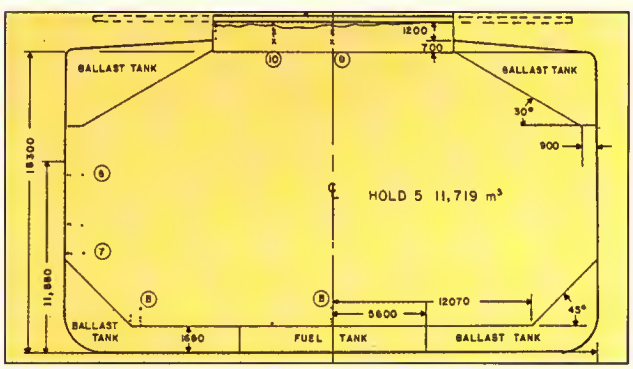
Samples taken from the outbound belt provided information on all quality characteristics.

Researchers used hand probes to obtain representative samples from each layer as the hold was loaded.

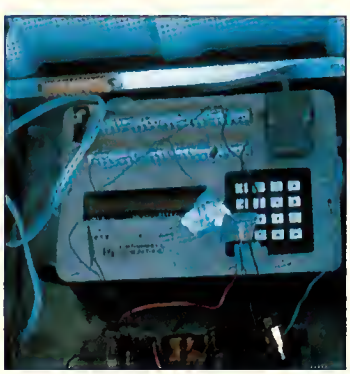
Researchers Followed Detailed Scientific Procedures to Discover What Causes a Decline in Corn Quality



The *Century Progress* at the loading berth, with all hatches open after receiving 2 million bushels of corn.



Temperature sensors were carefully positioned throughout one hold.



A computerized battery-powered recorder provided temperature and humidity readings every two hours throughout the four-week journey.

At the destination, researchers worked with the Japan Grain Inspection Agency to sample layers of corn as pneumatic suckers moved the corn to waiting barges and coasters. Samples were divided and shared with the Japan Grain Inspection Agency. Each sample was bagged and carefully labeled.

Researchers confer with Japanese importers on strategies for sampling during unloading.

A Japanese official inspected the cargo for possible insect infestation—none was found.

Samples were divided on the vessel and shared with Japanese inspection agencies.

When the hatches rolled open in the Japanese port (above), researchers and Japanese inspectors worked together to take probe samples from the top layer of the hold (right).

The temperature sensor's data logger was connected to a computer as soon as it was removed from the vessel, to obtain an immediate printout of the temperature changes. In the 1985 shipment, molds and fungi heated the corn above 117 °F during transit. Cooler temperatures during loading in 1986 slowed the mold growth.

A computer provided by the Japanese gave an immediate printout of several thousand temperature readings recorded during the voyage.

The percentage of broken kernels increased dramatically between the U.S. origin and Japanese processing plants.

Researchers analyzed some samples on-site for damage and BCFM even before unloading was finished.

Sculptured columns, caused by heating and mold growth, emerged during unloading.

Researchers immediately analyzed the samples for mold damage and BCFM to make sure there were no quality changes during shipment from Japan back to the U of I laboratory. They continued sampling the corn as it was moved from the vessel to Japanese barges, to determine what quality changes occurred during the unloading process.

Additional samples were taken from the barges as they were loaded from the ocean vessel.

Conclusion

These two case studies of shipments aboard the *Century Progress* are part of a series of five test shipments begun in 1974. Nine other vessels of corn were sampled at their destinations over a period of twelve months. Thousands of vessels of corn left U.S. ports during that time period, and the fourteen individual case studies do not provide a basis for predicting the average values of breakage or damage at destination. Rather, this research provides full-scale validation of laboratory results identifying factors causing quality losses.

The physical relationships among moisture, time, temperature, drying conditions, handling methods, and kernel characteristics that contribute to quality deterioration have been well documented in controlled experiments. These case studies, conducted by the University of Illinois, demonstrate to exporters and importers that the relationships hold under operating conditions in the commercial grain market channel and provide more realistic expectations for quality at the destination.

Knowing the physical limits of time, temperature, and moisture and knowing the relationships among drying, handling, and breakage answers the question of how to reduce quality losses. The physical relationships have been clearly established. Few economic incentives, however, encourage handlers at any point in the market channel to follow the recommendations. The incentives must start with identifying the relevant factors and factor limits in sales contracts and setting prices to reflect true differences in value. Changes in U.S. grades and marketing practices are also required in order to provide a common language and standard measurement technology to help buyers request the desired quality without having to develop a unique contract for each shipment.

Another ship waits its turn to berth at the export elevator, as researchers continue the search for better ways to ensure quality to the foreign buyers.

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